Principle and working of LED

Prerequisite/Recapitulations

- Knowledge of PN junction
- Biasing in PN junction

Objectives

After completion of this lecture students/ learners will be able to

- Understand the principle of LED
- Explain the working of LED

Introduction

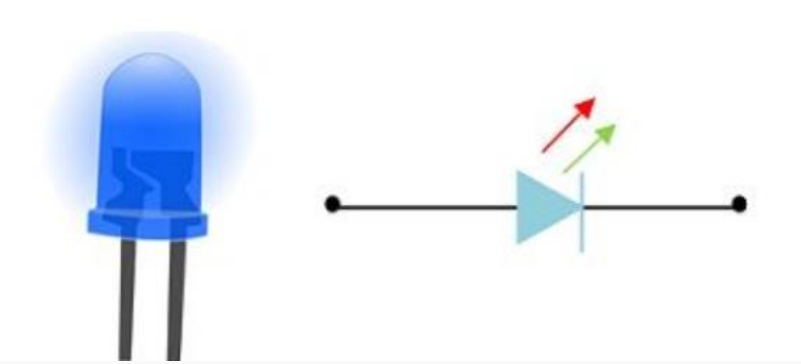
LED

LED is an abbreviation used for **Light Emitting Diode.**

It is basically a pn junction diode that has the ability to give off light when certain voltage is applied to it.

Introduction

LED (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminance. Electro-luminance is the property of the material to convert electrical energy into light energy and later it radiates this light energy. In the same way, the semiconductor in LED emits light under the influence of electric field.

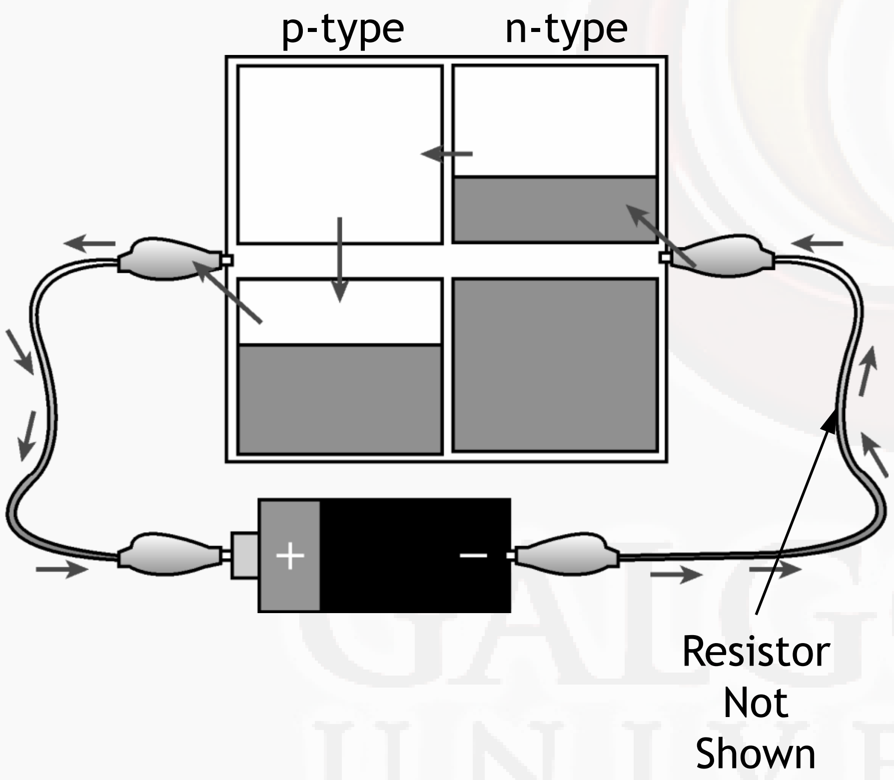


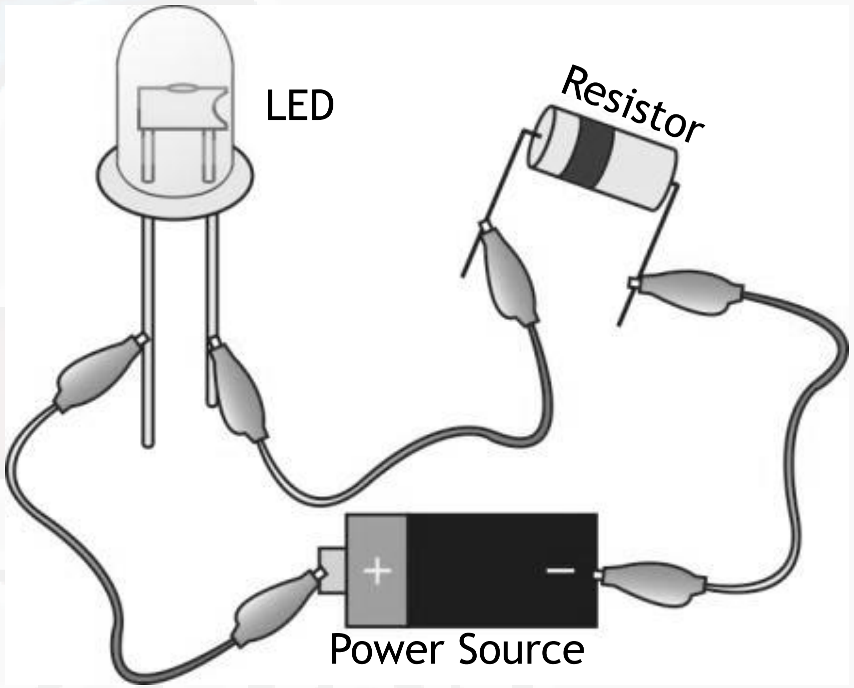
A Light emitting diode (LED) is essentially a pn junction diode. When carriers are injected across a forward-biased junction, it emits incoherent light. Most of the commercial LEDs are realized using a highly doped ‘n’ and a ‘p’ Junction.

LED

Introduction

p-n Junctions and LEDs



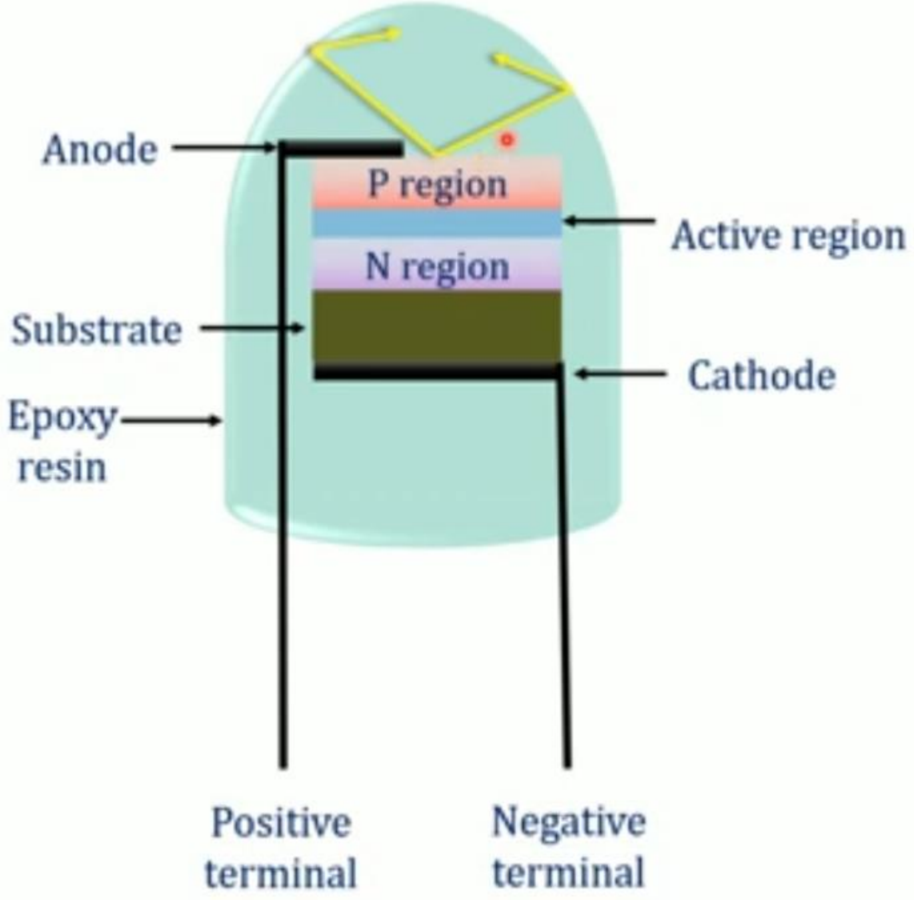


High energy electrons (n-type) fall into low energy holes (p-type)

Basis of LED construction

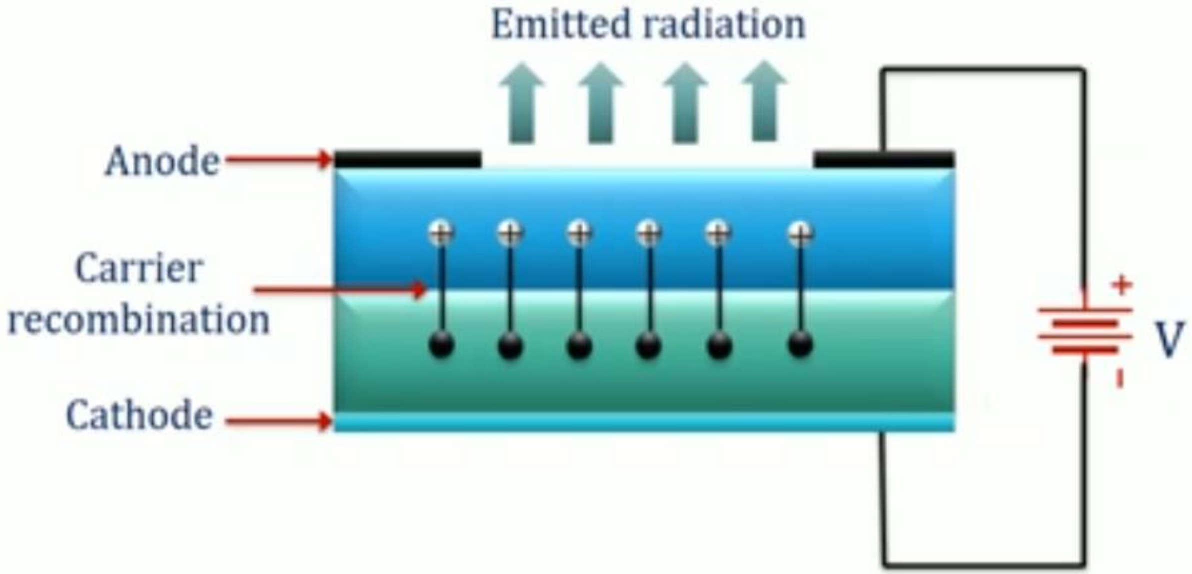
LED is formed by merging p and n type semiconductor material. However, the material used for its construction is usually GaAs, GaAsP or GaP.

It is majorly a forward biased device.



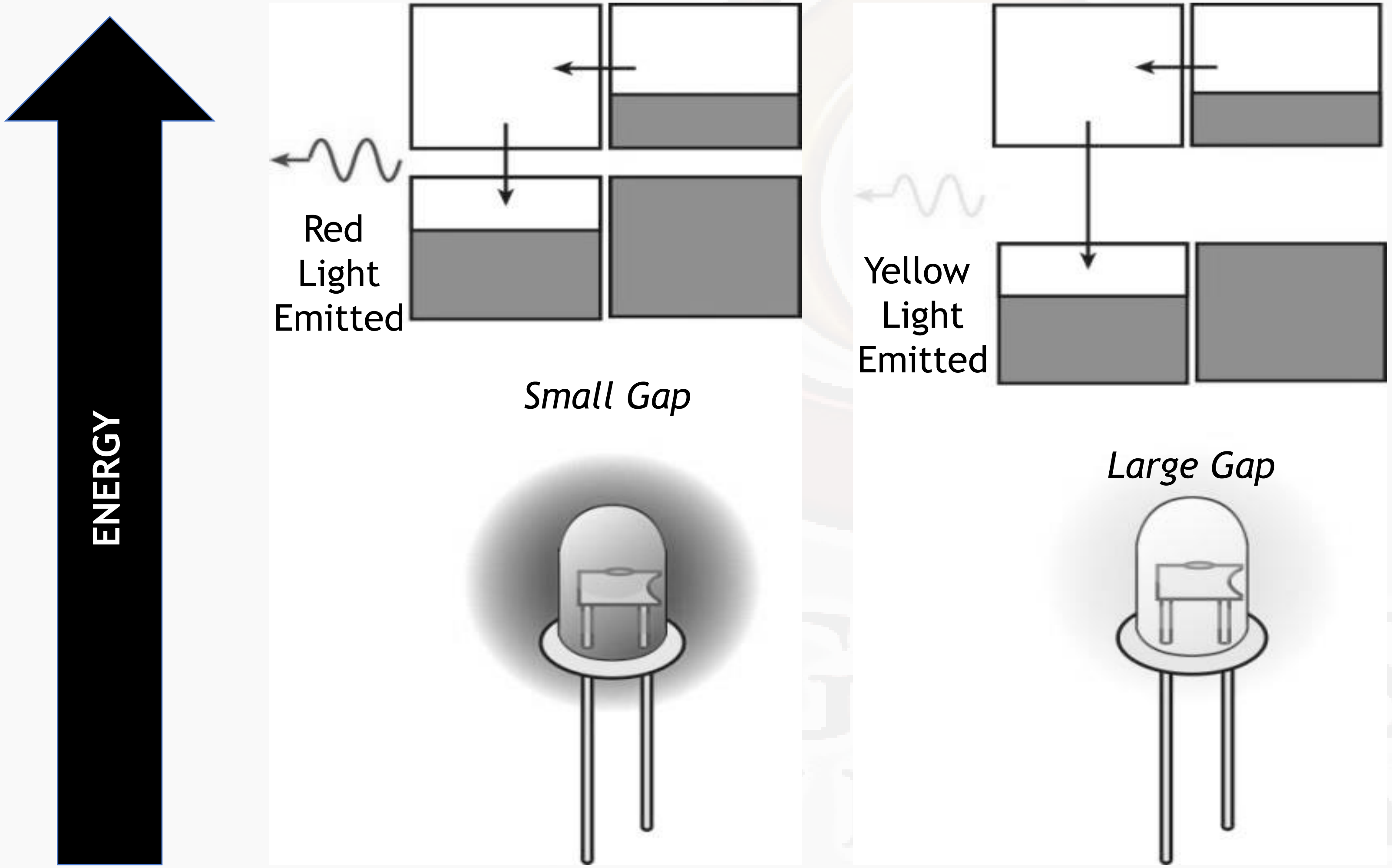
WORKING PRINCIPLE OF LED

LED works on the principle of **Electroluminescence**.



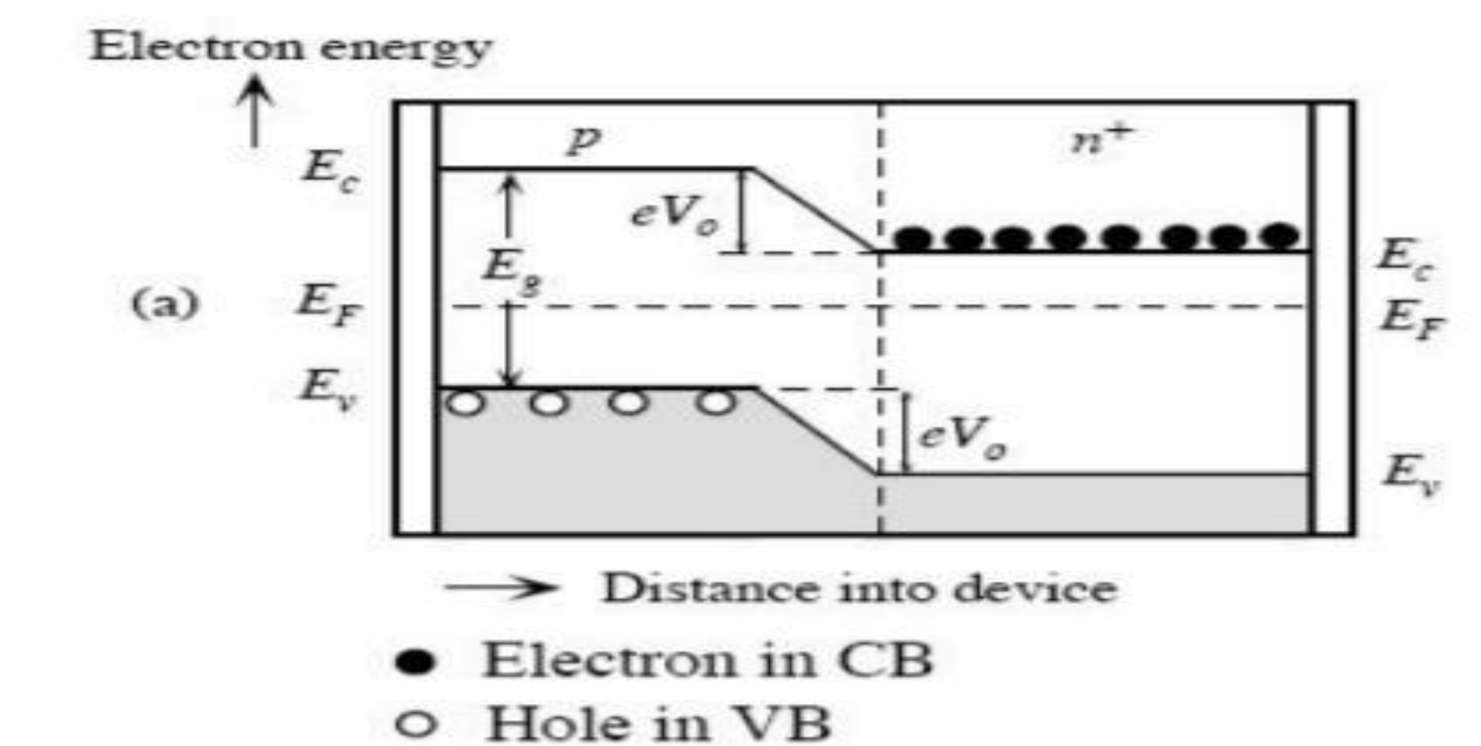
Electroluminescence is the property by which semiconductor material converts **electrical energy** into **light energy**.

p-n Junctions and LEDs



Principle:

To understand the principle, let's consider an unbiased pn+ junction (Figure shows the pn+ energy band diagram). The depletion region extends mainly into the p-side. There is a potential barrier from Ec on the n-side to the Ec on the p-side, called the built-in voltage,V0. This potential barrier prevents the excess free electrons on the n+ side from diffusing into the p side.



Principle

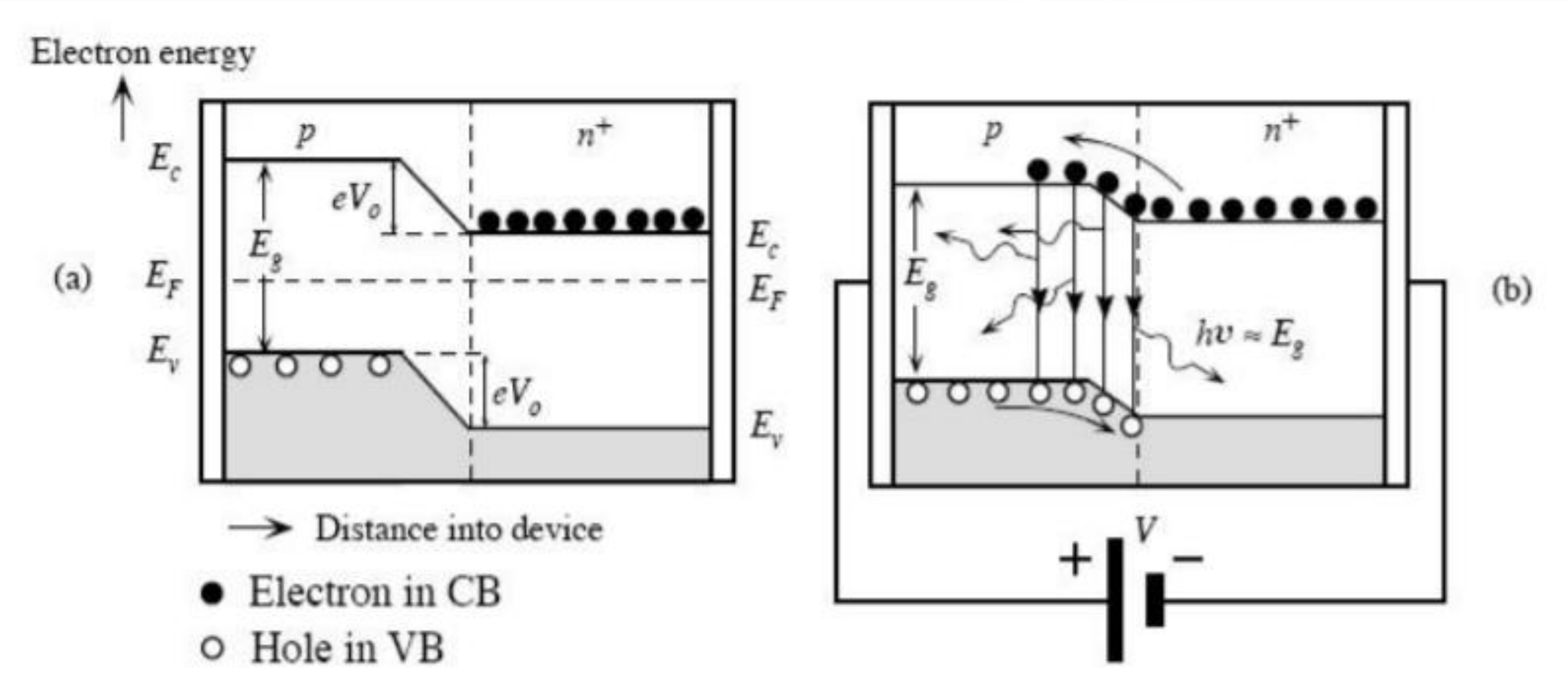


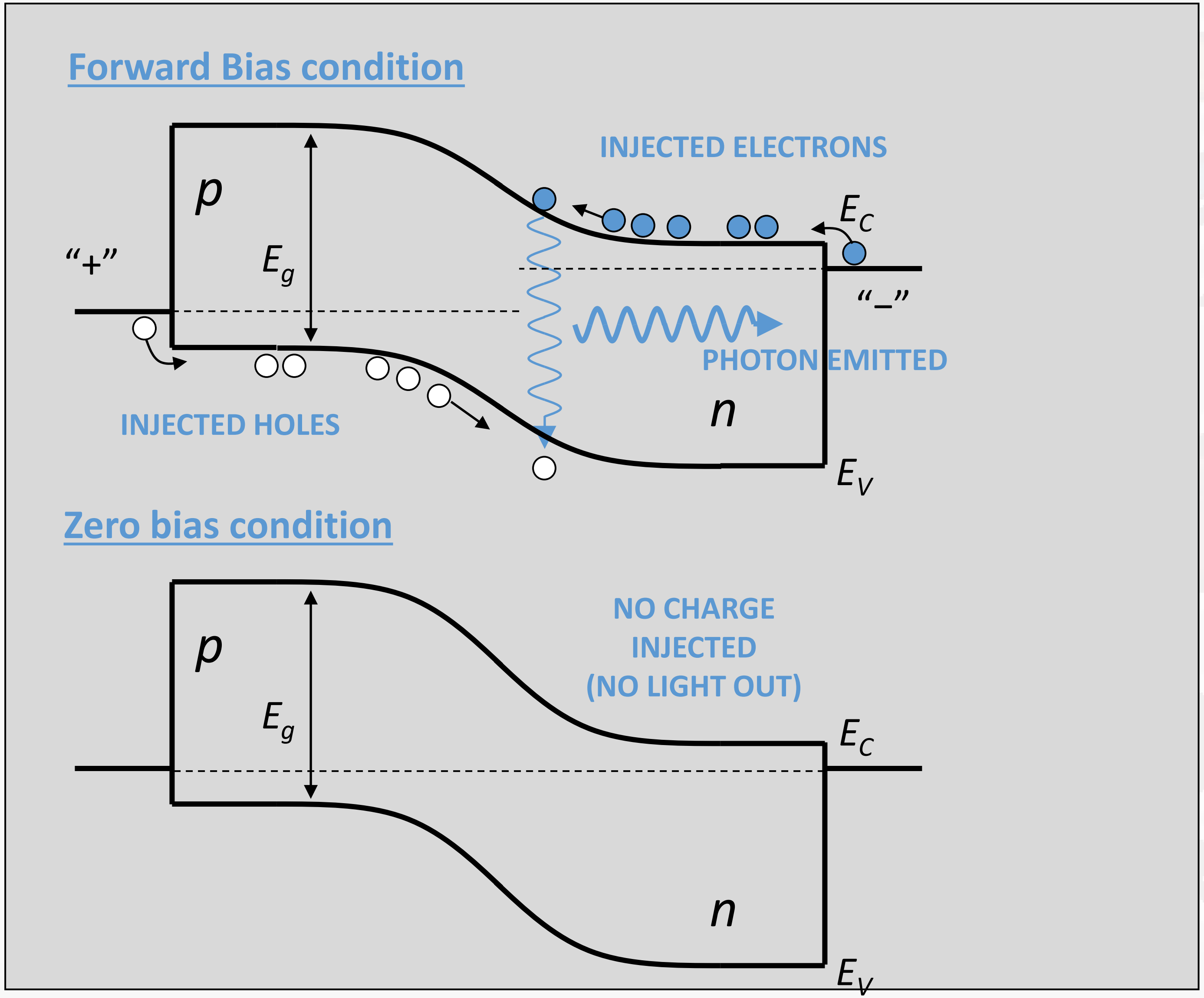
Figure 1: p-n+ Junction under Unbiased and biased conditions. (pn Junction Devices and Light Emitting Diodes by Safa Kasap)

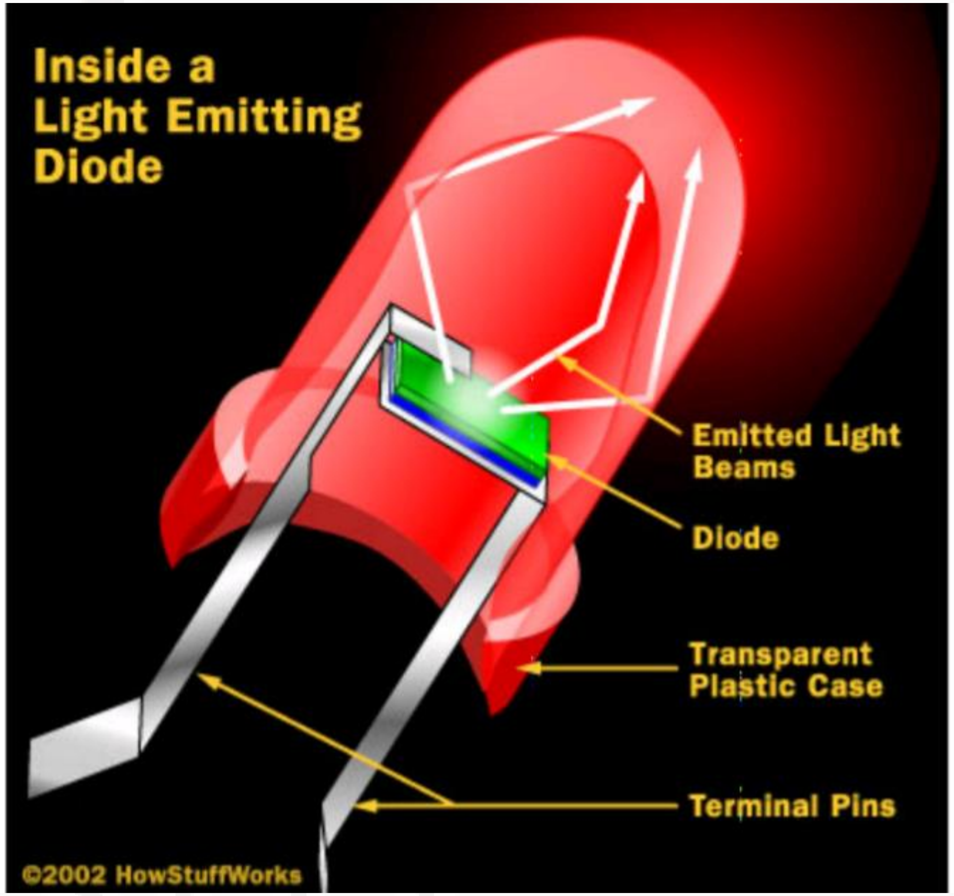
(a) The energy band diagram of a pn^+ (heavily n-type doped) junction without any bias. Built-in potential V_o prevents electrons from diffusing from n^+ to p side. (b) The applied bias reduces V_o and thereby allows electrons to diffuse or be injected into the p-side. Recombination around the junction and within the diffusion length of the electrons in the p-side leads to photon emission.

Principle

Homojunction p-n Light Emitting Diode

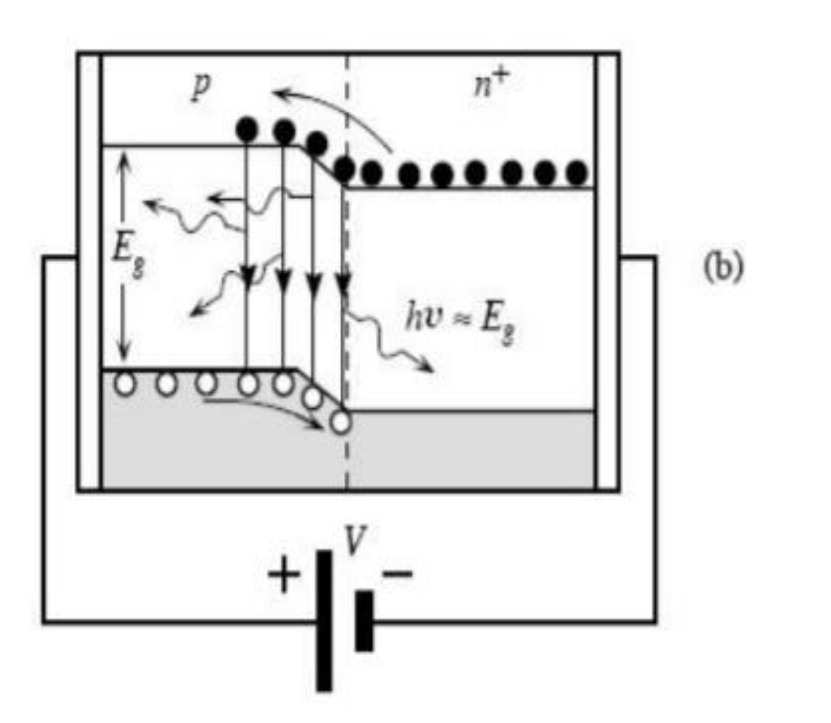
ELECTRICITY IN → LIGHT OUT





Principle

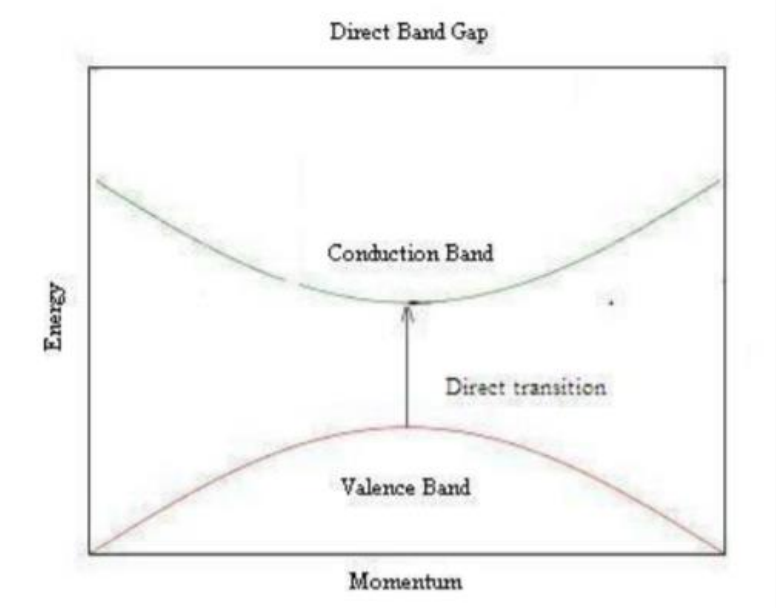
When a Voltage V is applied across the junction, the built-in potential is reduced from V0 to V0 – V. This allows the electrons from the n+ side to get injected into the p-side. Since electrons are the minority carriers in the p-side, **this process is called minority carrier injection**. But the hole injection from the p side to n+ side is very less and so the current is primarily due to the flow of electrons into the p-side. These electrons injected into the p-side recombine with the holes. This recombination results in spontaneous emission of photons (light). This effect is called injection electroluminescence. These photons should be allowed to escape from the device without being reabsorbed.



The recombination can be classified into the following two kinds • Direct recombination • Indirect recombination

Direct Recombination:

In direct band gap materials, the minimum energy of the conduction band lies directly above the maximum energy of the valence band in momentum space energ (Figure shows the E-k plot of a direct band gap material). In this material, free electrons at the bottom of the conduction band can recombine directly with free holes at the top of the valence band, as the momentum of the two particles is the same. This transition from conduction band to valence band involves photon emission (takes care of the principle of energy conservation). This is known as direct recombination. Direct recombination occurs spontaneously. GaAs is an example of a direct band-gap material.



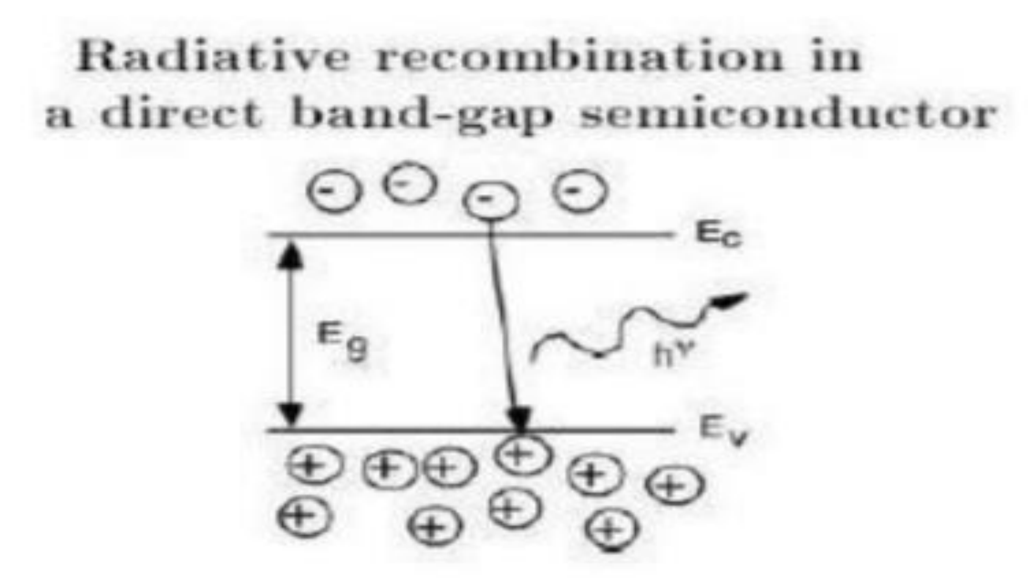
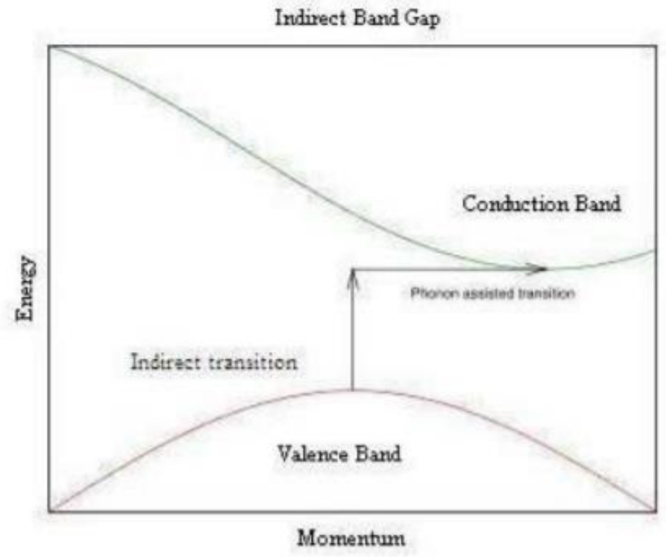


Figure: Direct Bandgap and Direct Recombination

Indirect Recombination:

In the indirect band gap materials, the minimum energy in the conduction band is shifted by a k-vector relative to the valence band. The k-vector difference represents a difference in momentum. Due to this difference in momentum, the probability of direct electron hole recombination is less. In these materials, additional dopants(impurities) are added which form very shallow donor states. These donor states capture the free electrons locally; provides the necessary momentum shift for recombination. These donor states serve as the recombination centers. This is called Indirect (non-radiative) Recombination. Figure shows the E-k plot of an indirect band gap material and an example of how Nitrogen serves as a recombination center in GaAsP. In this case it creates a donor state, when SiC is doped with Al, it recombination takes place through an acceptor level.



Addition of a nitrogen recombination center to indirectGaAsP

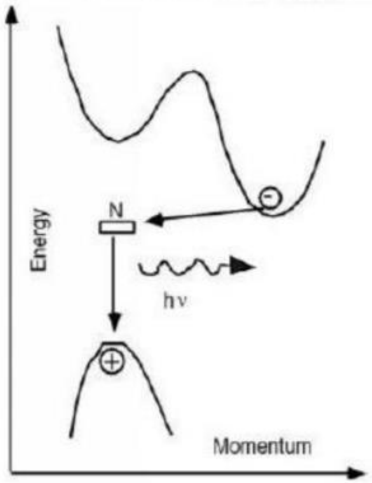


Figure : Indirect Bandgap and NonRadiative recombination

wavelength of the light emitted

The wavelength of the light emitted, and hence the color, depends on the band gap energy of the materials forming the p-n junction. The emitted photon energy is approximately equal to the band gap energy of the semiconductor. The following equation relates the wavelength and the energy band gap. $h\nu = E_g$, $hc/\lambda = E_g$, $\lambda = hc/E_g$

Thus, a semiconductor with a 2 eV band-gap emits light at about 620 nm, in the red. A 3 eV band-gap material would emit at 414 nm, in the violet.

The LEDs realized using two differently doped semiconductors that are the same material is called a homojunction. When they are realized using different bandgap materials they are called a heterostructure device. A heterostructure LED is brighter than a homoJunction LED.

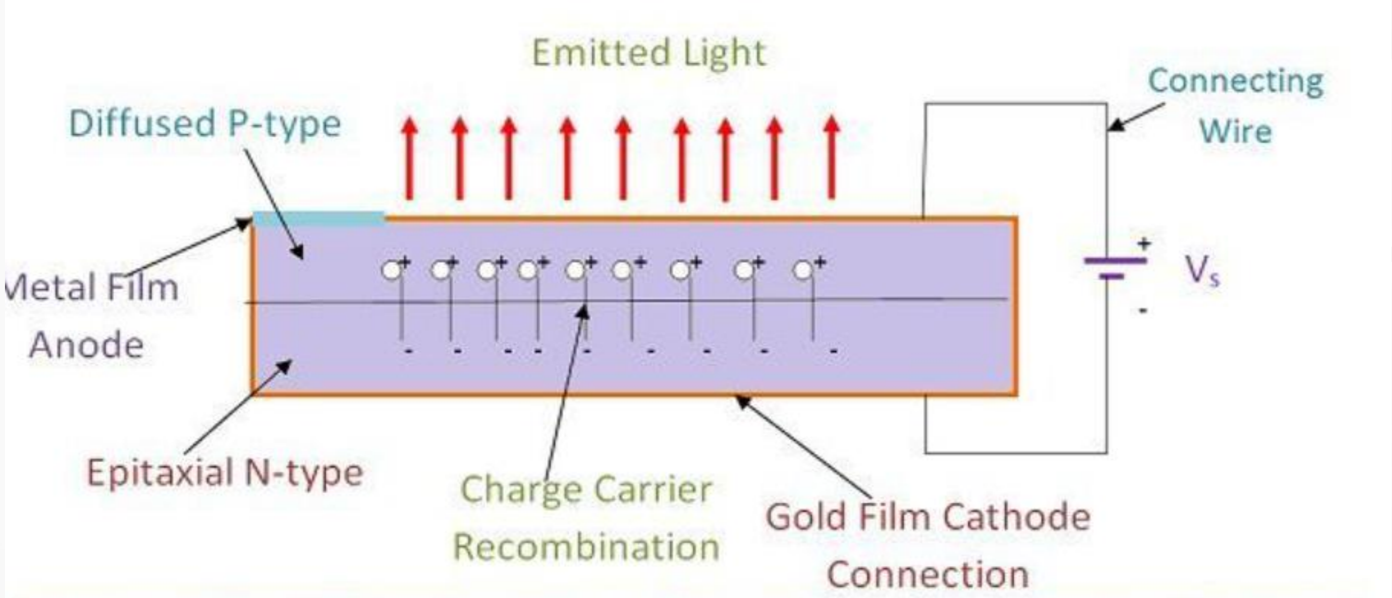
MATERIALS IN CONSTRUCTION	COLOUR	FORWARD VOLTAGE (IN VOLTS)
GaP	Green/Red	2.2
GaAsP	Yellow	2.2
GaAsP	Red	1.8
GaN	White	4.1
GaN	Blue	5.0
AlInGaP	Amber	2.1
AlInGaP	Yellow	2.1

LED Structure

The LED structure plays a crucial role in emitting light from the LED surface. The LEDs are structured to ensure most of the recombinations takes place on the surface by the following two ways.

By increasing the doping concentration of the substrate, so that additional free minority charge carriers electrons move to the top, recombine and emit light at the surface. • By increasing the diffusion length $L = \sqrt{D\tau}$, where D is the diffusion coefficient and τ is the carrier life time. But when increased beyond a critical length there is a chance of re-absorption of the photons into the device.

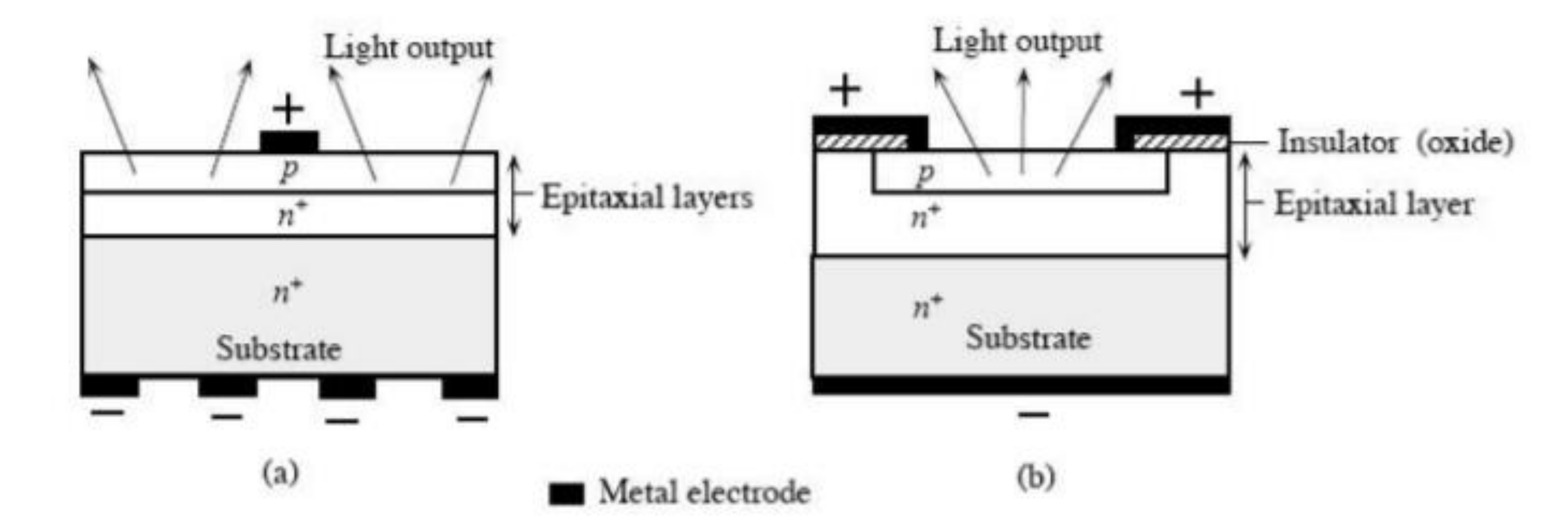
The LED has to be structured so that the photons generated from the device are emitted without being reabsorbed. One solution is to make the p layer on the top thin, enough to create a depletion layer.



The gold-film layer on N-type also provides reflection from the bottom surface of the diode.

LED structure

LEDs are usually built on an n-type substrate, with an electrode attached to the p-type layer deposited on its surface. P-type substrates, while less common, occur as well. Many commercial LEDs, especially GaN/InGaN, also use sapphire substrate.



A schematic illustration of typical planar surface emitting LED devices. (a) *p*-layer grown epitaxially on an n+ substrate. (b) First n+ is epitaxially grown and then *p* region is formed by dopant diffusion into the epitaxial layer.

LED structure

Applications of LED:

LED have a lot of applications. Following are few examples.

- Devices, medical applications, clothing, toys
- Remote Controls (TVs, VCRs)
- Lighting • Indicators and signs
- Optoisolators and optocouplers

Applications

Advantages of LED:

1.Temperature Range: It can be operated over a wide range of temperature ranging from 0^0C -70^0C

2.Switching Time: The Switching time of LEDs is in order of 1ns. Thus, they are useful in dynamic operations where a large number of arrays are used.

3.Low Power Consumption: They consume less power and they can be used even if the dc power supplied is low.

4.Better Controlling: The radiant power of LEDs is the function of the current flowing in it. Thus, the light intensity of LED can be controlled easily.

5.Economical and Reliable: LEDs are cheap and they possess a high degree of reliability.

6.Small Size and Portability: They are small in size and can be stacked together for the formation of alphanumeric displays.

7.Higher Efficiency: The efficiency of LEDs to convert power to light energy is 10-50 times greater than that of the tungsten lamp. The response time of LED is 0.1?S while in the case of tungsten lamp it is in tens or hundreds of milliseconds.

Disadvantages of LED

8.Overvoltage or Overcurrent: The LEDs may get damaged when the current is increased beyond a certain limit.

9.Overheating due to radiant power: It gets overheated with an excessive increase in radiant power. This may lead to damage of LED.

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